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Relaxation to a Phase-locked Equilibrium state in a One-dimensional Bosonic Josephson Junction

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Abstract:

The relaxation of isolated quantum many-body systems is a major unsolved problem of modern physics. It connects to many fundamental questions, ranging from the state of the early universe and heavy-ion collisions to the electron dynamics in condensed matter physics. However, realizations of quantum many-body systems which are both well isolated from their environment and accessible to experimental study are scarce. In recent years, the field has experienced rapid progress, partly attributed to the unprecedented insights provided by ultra-cold atoms.

In this thesis, we present the experimental study of a relaxation phenomenon occurring between two elongated coupled superfluids. This system, known as one-dimensional Bosonic Josephson junction (1D-BJJ), benefits from numerous advantages. From the experimental point of view, the 1D-BJJ presents the versatility, high controllability and isolability characteristic to ultra-cold atom systems. This allows a rigorous and wide-ranging study of the relaxation. From the theoretical point of view, the 1D-BJJ benefits from extensive theoretical work provided in particular by the sine-Gordon model. This model has proven successful in describing the equilibrium dynamics of two coupled 1D atomic superfluids up to very high order correlations. However, it fails to describe the relaxation we observe and it is therefore strongly challenged by this work.

In a first set of experiments, a well-defined non-equilibrium state is created by coherent splitting of a single one-dimensional Bose gas into two halves. A precise difference of phase between the two halves is introduced while preserving a high phase coherence. The subsequent dynamics exhibits a relaxation to a phase-locked equilibrium state, the time scale of which exceeds the theoretical expectations. We support the experimental results with an empirical model that allows quantitative discussions. Various experimental parameters, among which the atom number and the tunnel coupling strength are varied to investigate their impact on the relaxation mechanism and to help determining its origin.

The second experiment investigates the dynamics of a pair of 1D Bose gases differing by their atomic density. In this case, the system presents a more complex distribution of excitations and its dynamics exhibits a threshold above which the relaxation is dominated by a dephasing. It provides additional insights into the relaxation mechanism as some experimental parameters, such as the trap geometry, become in this case more relevant than in the first set of experiments.

These observations attest to the existence of a relaxation phenomenon in a 1D-BJJ and illustrate how strongly the non-equilibrium dynamics differ from the equilibrium one well described by thermodynamics and statistical physics.